Specification for an Integrated Nuclear Energy Economic Model

In December 2002, the Generation IV International Forum (GIF) issued ***A Technology Roadmap for Generation IV Nuclear Energy Systems.*** The Roadmap recognizes the benefits of an essential role for nuclear energy in supplying the energy needs of an expanding world community in the 21st century. Goals are established against which advanced nuclear energy systems can be evaluated to assure that safe, sustainable, proliferation-resistant, and economic nuclear energy systems are available for deployment in the 2030 time frame. The research and development needed to bring advanced nuclear energy systems to a state of readiness are also specified.

The importance of economic competitiveness is recognized in the Roadmap by the establishment of specific goals that Generation IV nuclear energy systems have (1) a life-cycle cost advantage over other energy sources and (2) a level of financial risk comparable to other energy projects. The economic goals are expressed in the Roadmap by criteria and metrics: (1) total capital investment cost of the production system (reactor and balance of plant) and (2) levelised unit electricity/product cost (LUEC). Also, it was recognized that new calculation tools should be developed for the economic evaluation of advanced nuclear energy systems, in particular, calling for the implementation of an integrated economic assessment model.

This “Specification” sets forth the objectives, scope, target users, data requirements, and structure of an Integrated Nuclear Energy Economics Model (INEEM). Key aspects driving the model specification are listed below. The main objective of the INEEM is to provide a robust and transparent tool for assisting in the economic evaluation of nuclear energy systems at an early stage of conceptual design and development by providing a “level playing field” framework with which to evaluate diverse nuclear technologies at appropriate times in their phases of development. The nuclear energy systems to be assessed are – and will continue to be, at least in the coming decade – far from commercial deployment. The model will, therefore, address uncertainties inherent to reactor and fuel cycle concepts not yet fully developed. The INEEM will be designed to accommodate all reactor types being considered within GIF (i.e., GFR, LFR, MSR, SCWR, SFR and VHTR) and their fuel cycles. The multinational GIF context calls for reflecting in the model economic conditions of different countries. The main users of the INEEM will be the system design teams, likely at the level of the System Integration Steering Committees, and the Experts Group of GIF. Data requirements and outputs will be adapted to these users.

The structure of the INEEM consists of several models covering different elements of economic assessment (e.g., capital costs, fuel cycle costs, electricity and non-electrical product costs) which are integrated within one model that allows a comprehensive evaluation of the economic performance of Generation IV nuclear energy systems. Uncertainties in cost elements and performance of the systems will be treated in each model and contingencies will be calculated. The impact of building a series of small units rather than one large plant on investment per unit of installed capacity and on production cost is addressed. Finally, the integrated model also has the capability to assess the costs of all relevant stages in the development of Generation IV nuclear energy systems, including the planning, research, development, demonstration (including prototype), deployment, and commercial stages.

The main modules of the INEEM are:

1. Construction/Production Models, including

    1.1. Construction-Capital Cost Model (CCM)
    1.2. Production Cost Model (PCM)
    1.3. Energy Products Cost Model (EPCM)
    1.4. Plant Size Model (PSM)
    1.5. RD&D Cost Code of Accounts (RDDCOA)

2. Fuel Cycle Cost Model (FCM)

Figure 1 shows the basic structure and relationships in the INEEM. Market demands and the interaction between markets for alternative products (e.g., electricity and hydrogen) are important external inputs for the INEEM. The INEEM does not predict future energy demand or prices, but relies on exogenous input data specifying the demand for nuclear capacity, i.e., size of the commercial fleet in numbers of units and/or total capacity.

Figure 1. Simplified Structure of the INEEM

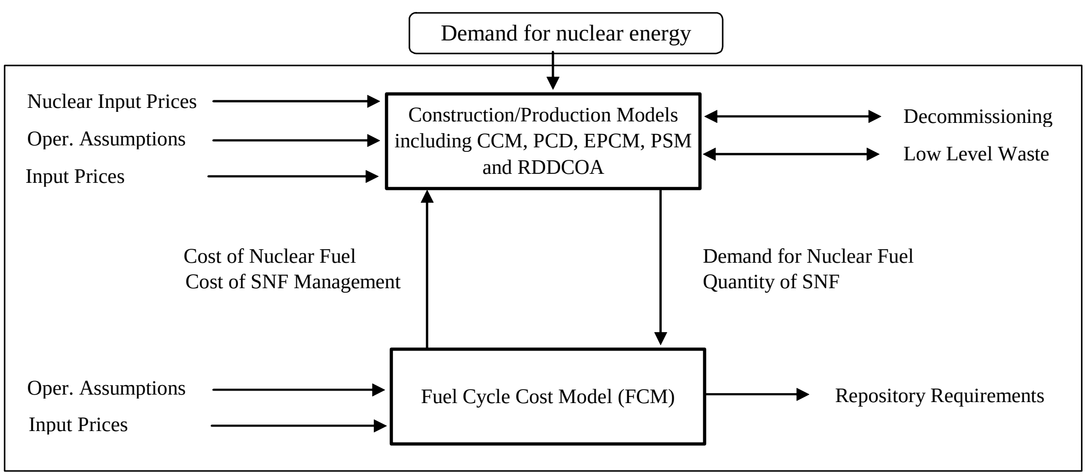
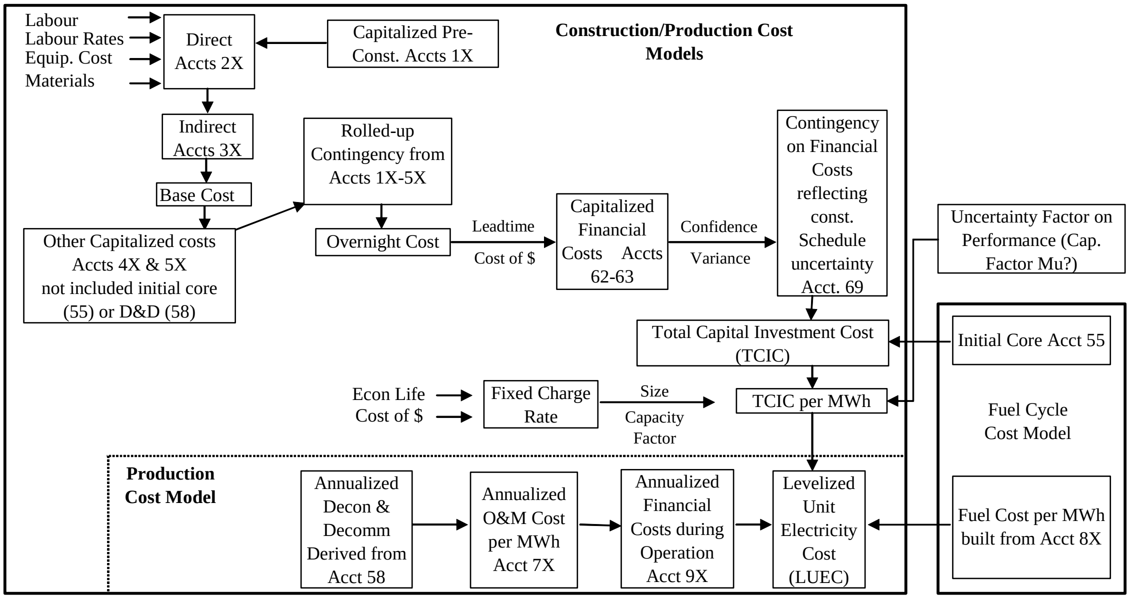


Figure 2 provides a schematic lay out of the structure of the INEEM and indicates the links between the main modules.

Figure 2. Structure and Logic of the Construction/Production and Fuel Cost Models in Determining the Levelized Unit Cost of Electricity[1]



The specification of each module provided below covers overall purpose, structure, scope, input data (including proposed default values when applicable), and outputs/results. All the technical and economic data required to run the INEEM are exogenous to the model but default data will be proposed to users whenever relevant to facilitate their task or to provide a common basis for comparison (e.g., labor costs in various regions, plant capacity factor, and economic lifetime).

The main outcomes/results of the INEEM provide an evaluation of the metrics adopted in the Roadmap to measure the economic goals of GIF: (1) total investment cost, including interest during construction (IDC), and (2) levelised unit cost of electricity (LUEC) and/or other products, if applicable.

The INEEM input data include basic design detail (systems and components), characteristics of the nuclear energy system considered and generic economic assumptions that will be used in all sub-models. The main plant characteristics needed are (1) capacity (e.g., MWe or tonnes of H_2/year), (2) plant economic lifetime, (3) average availability factor, and (4) Operation and Maintenance (O&M) costs. If the plant is multipurpose, e.g., produces electricity and potable water, details on its operation mode will be required as input data. One of the main economic inputs is the real discount rate, assuming a currency and year of reference (e.g., 2001 US dollars).

[1] In figures 2 and 3, “Accts XX” refer to the GIF Code Of Accounts nomenclature.

1. Construction/Production Models

1.1. Construction-Capital Cost Model (CCM)

The CCM is designed to calculate the Total Capital Investment Cost (TCIC), expressed in monetary unit of the reference year, e.g., in 2001 dollars, of a nuclear energy system, thus providing one metric for evaluating the financial risk goal of GIF. In addition to being a metric for GIF economic goals, it provides input data for the production cost model. The CCM itself includes several sub-models dedicated to the calculation of (1) base cost, (2) contingencies, and (3) interest during construction.

The scope of the CCM covers all capital investments needed during the lifetime of the nuclear energy system considered, including: capital cost of the nuclear island and balance of plant for generating electricity or other products, e.g., hydrogen; first core cost; and major refurbishment and decommissioning costs not included in routine O&M costs.

The CCM is designed to estimate the capital investment cost of a fully developed system (N^{th}-of-a-kind) and does not include capital costs related to R&D which are captured in another sub-model of the INEEM. The CCM, however, includes guidance and algorithms to evaluate cost evolution from First-of-a-kind plant to N^{th}-of-a-kind plant The scope of the CCM does not include financing or tax aspects that will be addressed within a business plan when a nuclear energy system is ordered and built.

The basic feature of the CCM is to provide a comprehensive framework, a Code Of Accounts (COA), which can be used to calculate the TCIC of a nuclear system as the sum of individual equipment and services (including labor) costs. It is recognized that this approach is standard for systems at an advanced level of design development and may be too detailed for some GEN IV systems at present. However, it provides a systematic checklist at various levels of detail that can be applied to advanced systems, even at an early stage of design. The COA covers all equipment required to produce electricity and/or other products, such as heat, potable water, and hydrogen.

The CCM includes options to evaluate the cost of advanced equipment and innovative systems through scaling, interpolation and extrapolation from known costs of existing equipment and nuclear power plants, taking into account size and series effects, and other relevant data. Guidance will be provided on the selection of a reference model for this top-down scaling approach which allows early cost evaluation of less well-developed designs.

The input data for the CCM include all the cost items listed in the COA. However, the user may choose to provide aggregated costs at various levels of detail, particularly where modular procurement and construction techniques are used. Contingencies are specified based on uncertainties in cost estimation as a function of the state of maturity of the design. The calculation of IDC requires the user to provide as input data the schedule of expenses month-by-month or specifies the use of a cumulative expenditure (“S”) curve when detailed schedule information is not available. Generic country or region specific economic data will be provided as default values, but may be changed by the user.

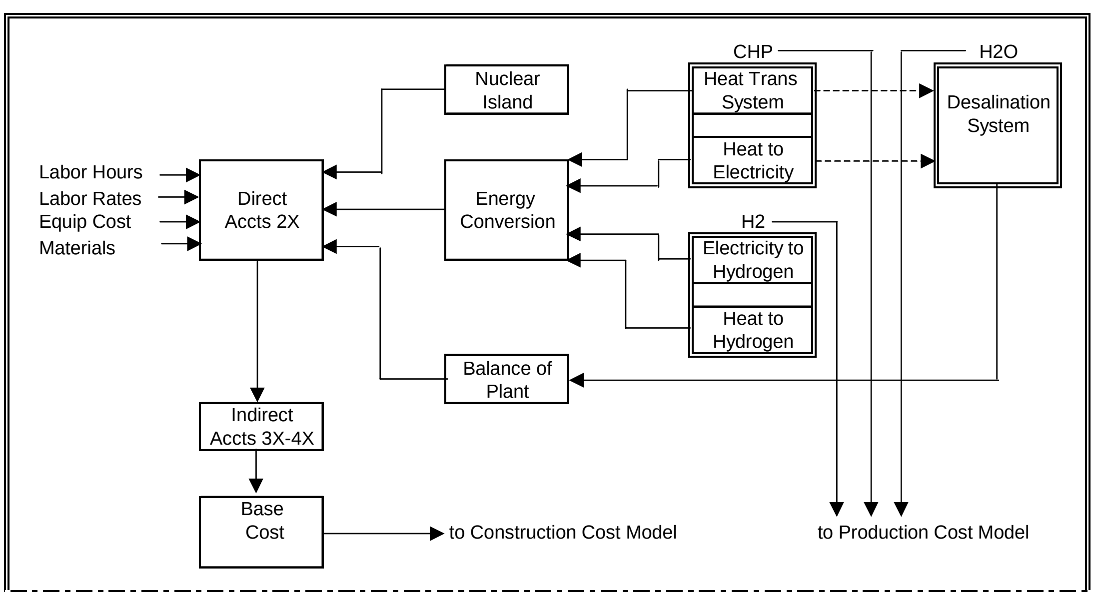
1.2. Production Cost Model (PCM)

The PCM calculates the levelised production cost, e.g., levelised unit of electricity cost (LUEC) for electricity generation plants of the system, in monetary unit per unit of product generated (e.g., \$/kWh or \$/tonnes of H_2). The scope of the PCM covers all costs incurred to produce electricity or other products, i.e., capital investment, O&M, and fuel cycle costs. The capital investment cost is provided by the CCM and the fuel cycle cost by the FCM.

1.3. Energy Products Cost Model (EPCM)

The EPCM addresses multiple energy product economics, including trade-offs between: low cost electricity generation; process heat application, such as hydrogen production ("Heat to Hydrogen" in Figure 3), desalination (requiring either heat or electricity, or both), district heating (through the "Heat Transmission System" in Figure 3); and actinide burning for radioactive waste minimization (not represented in Figure 3). For multiple product production, each product must be priced to cover its variable (marginal) costs. Allocating the fixed costs of production between different products (or classes of customers) is accomplished by the appropriate considerations of efficiency and equity. Products may be directed toward regulated, deregulated, or mixed markets. The joint production of electricity and hydrogen, or other process heat applications is evaluated with respect to trade-offs under various regulatory and competitive environments, and product-end uses. The joint production of electricity and actinide management services is evaluated with respect to the price that would be required to make such services viable.

Figure 3. Energy Products Cost Model

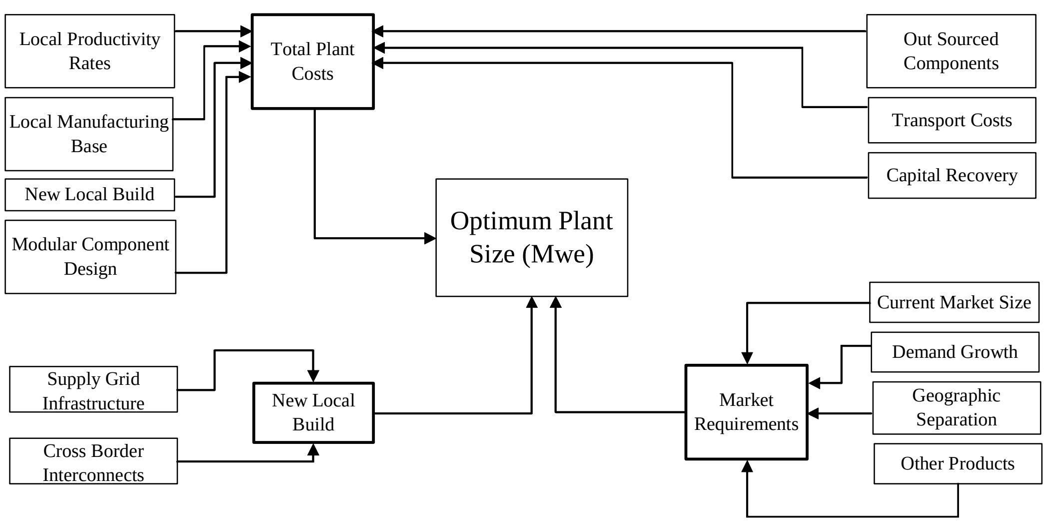


Specific cost elements for the secondary and/or intermediate portions of the plant obtained through the technical research and design information are input into detailed COA for RD&D and capital costs. These cost elements will supplement or replace the electricity generating equipment. Specific costs may be derived from a top-down approach using a specified reference model or by a bottom-up approach from specific design information as the system design matures. For conventional production methods, such as electrolysis ("Electricity to Hydrogen" in Figure 3), known costs may be used for the main processing systems and such intermediate systems for nuclear application developed by COA. Operating and maintenance costs unique to the product being produced must be specified, in addition to the nuclear O&M costs. The model will then calculate the Levelized Unit Product Cost for the product under consideration.

1.4. Plant Size Model (PSM)

The construction of small modular nuclear plants versus large plants is compared by accounting for the costs of these two types of nuclear energy systems. Cost factors involved in the construction of a small modular plant that are not encountered, and not accounted for, in the "conventional" cost computation of a large plant are included to evaluate the economics of plant size. The basic issue explored is whether economy of scale can be overcome by additional economies of fabrication, operation, and learning (series) effects coupled with the earlier revenue stream possible with sequential module installation. It is necessary to make such comparisons at a total installed capacity (e.g., 15,000 MWe) that assures an N^{th}-of-a-kind comparison of large versus small plants.

Figure 4. Plant Size Model



Since plant systems, structures, and components for both large and small plants can be made of modular equipment and system manufacture (either in a remote factory or in an on-site fabrication shop), this model also provides the ability to account for modular construction applications in the large plant capital/production cost model. In both cases relatively low productivity on-site labor is replaced by higher productivity factory labor, while accounting for the extra cost of constructing the module factory, such as higher salaries for the factory, and incremental costs of completed module shipment to the construction site. Additional inputs will be required for factory capital costs, capital recovery requirements, factory labor and productivity rates, construction/installation/ operation schedules, and unique transportation costs.

1.5. Research, Development, & Demonstration Cost Code of Accounts

A COA is available to account for expenditures that are required before commercialization. While these costs are not amortized in the Levelized Unit Energy Cost, this COA provides a method for comparing RD&D expenditures across technologies, including fuel cycle expenditures.

2. Fuel Cycle Cost Model (FCM)

The FCM is designed to calculate the average levelised lifetime cost of the fuel cycle, expressed in monetary unit per unit of product (e.g., $/MWh). It provides an input to the production cost model. The INEEM includes the first core cost in the capital cost. The average fuel cycle cost is calculated in the FCM assuming that requirements and performance can be averaged over the economic lifetime of the plant.

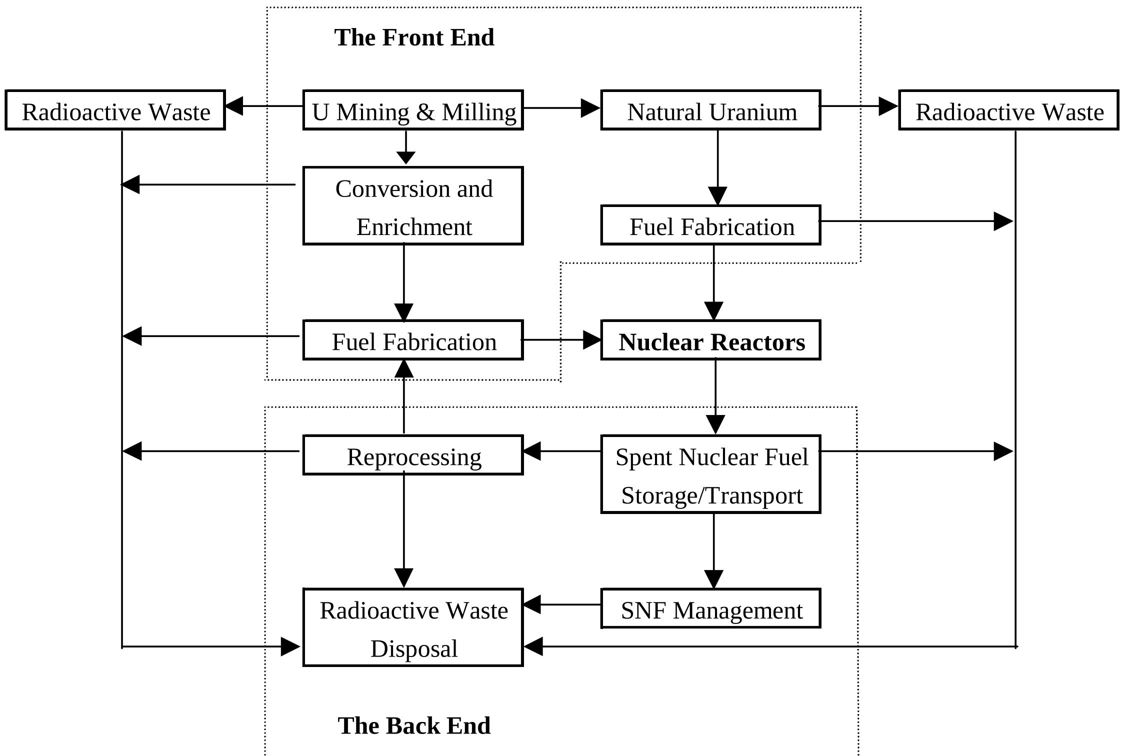
The scope of the FCM covers all stages of the fuel cycle from fissile – and fertile if applicable – material provision, e.g., uranium mining or plutonium extraction from spent fuel, through enrichment (if applicable), and fuel fabrication (see diagram) to final disposal of spent fuel or high level waste.

The structure of the FCM depends on the fuel cycle option and on the technology preparedness of individual fuel cycle processes. At each stage of the fuel cycle (e.g., enrichment or fabrication) the user may choose to either (1) enter a price for the service needed (e.g., $/SWU) or (2) calculate the cost of the service based upon technical and economic characteristics of the facility providing it.

The first option will apply to materials such as natural uranium and services, such as spent fuel transportation for which market prices are available from past experience and may be found in published literature. The prices of nuclear materials and services are input data exogenous to the model. Default values or ranges will be provided to assist the user. When relevant, real price escalation rates can be applied.

The second option applies to innovative processes for which there is no commercial experience to date. It will require the user to enter data on the facility providing the service including its capacity, investment, and operation costs. The FCM will provide a COA for fuel cycle facilities to assist the user in calculating the investment cost of the plant. The unit cost of the service or product will be calculated by the model using the methodology adopted to calculate the LUEC. Input data in that case will include (in addition to those entered in the COA) the capacity and economic lifetime and the marginal production costs, e.g., operation, maintenance, and consumables.

Figure 5. Fuel Cycle Model (arrows represent material flows)



In both cases, the quantities of materials and services required at each step of the fuel cycle and schedule of payment for those materials and services will be exogenous input data. Economic parameters such as discount rate are generic input data of INEEM that will remain similar in all modules unless otherwise justified.